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(54) **LOBULAR ELASTIC TUBE ALIGNMENT
SYSTEM FOR PROVIDING PRECISE
FOUR-WAY ALIGNMENT OF COMPONENTS**

1,261,036 A 4/1918 Kerns
(Continued)

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FOREIGN PATENT DOCUMENTS

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BE 842302 A 9/1976
CN 1036250 A 10/1989

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(Continued)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,219,398 A 3/1917 Huntsman

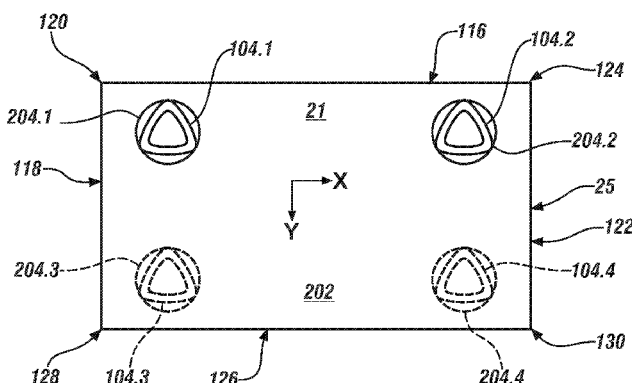
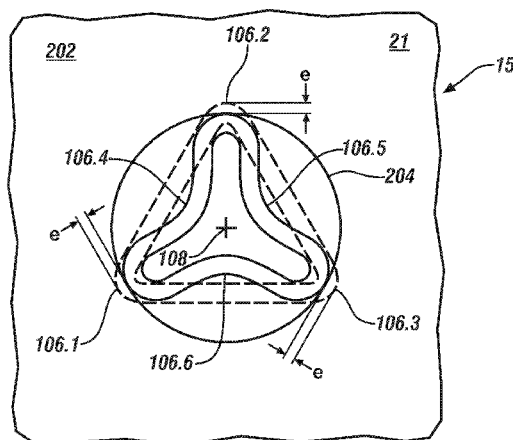
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(57) **ABSTRACT**

An elastically averaged alignment system includes a first component and a second component. The first component includes a first alignment member and an elastically deformable alignment element fixedly disposed with respect to the first alignment member. The second component includes a second alignment member and an alignment feature fixedly disposed with respect to the second alignment member. The elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the alignment feature. The elastically deformable alignment element includes a lobular hollow tube having a cross-section having at least three outwardly oriented lobes relative to a central axis of the hollow tube, and the alignment feature includes a circular aperture. Portions of the elastically deformable alignment element when inserted into the alignment feature elastically deform to an elastically averaged final configuration that aligns the first alignment member with the second alignment member in four planar orthogonal directions.

15 Claims, 5 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

1,301,302	A	4/1919	Nolan	4,394,853	A	7/1983	Lopez-Crevillen et al.
1,556,233	A	10/1925	Maise	4,406,033	A	9/1983	Chisholm et al.
1,819,126	A	8/1931	Scheibe	4,477,142	A	10/1984	Cooper
1,929,848	A	10/1933	Neely	4,481,160	A	11/1984	Bree
1,968,168	A	7/1934	Place	4,527,760	A	7/1985	Salacuse
1,982,076	A	11/1934	Spahn	4,575,060	A	3/1986	Kitagawa
2,006,525	A	7/1935	Thal	4,599,768	A	7/1986	Doyle
2,267,558	A	12/1941	Birger et al.	4,605,575	A	8/1986	Auld et al.
2,275,103	A	3/1942	Gooch et al.	4,616,951	A	10/1986	Maatela
2,275,900	A	3/1942	Hall	4,648,649	A	3/1987	Beal
2,385,180	A	9/1945	Allen	4,654,760	A	3/1987	Matheson et al.
2,482,488	A	9/1949	Franc	4,745,656	A	5/1988	Revlett
2,560,530	A	7/1951	Burdick	4,767,647	A	8/1988	Bree
2,612,139	A	9/1952	Collins	4,805,272	A	2/1989	Yamaguchi
2,688,894	A	9/1954	Modrey	4,807,335	A	2/1989	Candea
2,693,014	A	11/1954	Monahan	4,817,999	A	4/1989	Drew
2,707,607	A	5/1955	O'Connor	4,819,983	A	4/1989	Alexander et al.
2,778,399	A	1/1957	Mroz	4,865,502	A	9/1989	Maresch
2,780,128	A	2/1957	Rapata	4,881,764	A	11/1989	Takahashi et al.
2,862,040	A	11/1958	Curran	4,973,212	A	11/1990	Jacobs
2,902,902	A	9/1959	Slone	4,977,648	A	12/1990	Eckerud
2,946,612	A	7/1960	Ahlgren	5,005,265	A	4/1991	Muller
2,958,230	A	11/1960	Haroldson	5,039,267	A	8/1991	Wollar
3,005,282	A	10/1961	Christiansen	5,139,285	A	8/1992	Lasinski
3,014,563	A	12/1961	Bratton	5,154,479	A	10/1992	Sautter, Jr.
3,087,352	A	4/1963	Daniel	5,165,749	A	11/1992	Sheppard
3,089,269	A	5/1963	McKiernan	5,170,985	A	12/1992	Killworth et al.
3,130,512	A	4/1964	Van Buren, Jr.	5,180,219	A	1/1993	Geddie
3,152,376	A	10/1964	Boser	5,208,507	A	5/1993	Jung
3,168,961	A	2/1965	Yates	5,212,853	A	5/1993	Kaneko
3,169,004	A	2/1965	Rapata	5,234,122	A	8/1993	Cherng
3,169,439	A	2/1965	Rapata	5,297,322	A	3/1994	Kraus
3,188,731	A	6/1965	Sweeney	5,339,491	A	8/1994	Sims
3,194,292	A	7/1965	Borowsky	5,342,139	A	8/1994	Hoffman
3,213,189	A	10/1965	Mitchell et al.	5,368,427	A	11/1994	Pfaffinger
3,230,592	A	1/1966	Hosea	5,368,797	A	11/1994	Quentin et al.
3,233,358	A	2/1966	Dehm	5,397,206	A	3/1995	Sihon
3,233,503	A	2/1966	Birger	5,407,310	A	4/1995	Kassouni
3,244,057	A	4/1966	Mathison	5,446,965	A	9/1995	Makridis
3,248,995	A	5/1966	Meyer	5,507,610	A	4/1996	Benedetti et al.
3,291,495	A	12/1966	Liebig	5,513,603	A	5/1996	Ang et al.
3,310,929	A	3/1967	Garvey	5,524,786	A	6/1996	Skudlarek
3,413,752	A	12/1968	Perry	5,538,079	A	7/1996	Pawlick
3,473,283	A	10/1969	Meyer	5,556,808	A	9/1996	Williams et al.
3,531,850	A	10/1970	Durand	5,566,840	A	10/1996	Waldner
3,551,963	A	1/1971	Long	5,575,601	A	11/1996	Skufca
3,643,968	A	2/1972	Horvath	5,577,301	A	11/1996	DeMaagd
3,680,272	A	8/1972	Meyer	5,577,779	A	11/1996	Dangel
3,800,369	A	4/1974	Nikolits	5,580,204	A	12/1996	Hultman
3,841,044	A	10/1974	Brown	5,586,372	A	12/1996	Eguchi et al.
3,842,565	A	10/1974	Brown et al.	5,593,265	A	1/1997	Kizer
3,845,961	A	11/1974	Byrd, III	5,601,453	A	2/1997	Horchler
3,847,492	A	11/1974	Kennicutt et al.	5,629,823	A	5/1997	Mizuta
3,860,209	A	1/1975	Strecker	5,634,757	A	6/1997	Schanz
3,895,408	A	7/1975	Leingang	5,657,516	A	8/1997	Berg et al.
3,897,967	A	8/1975	Barenyl	5,667,271	A	9/1997	Booth
3,905,570	A	9/1975	Nieuwveld	5,670,013	A	9/1997	Huang et al.
3,972,550	A	8/1976	Boughton	5,698,276	A	12/1997	Mirabatur
3,988,808	A	11/1976	Poe et al.	5,736,221	A	4/1998	Hardigg et al.
4,035,874	A	7/1977	Liljendahl	5,765,942	A	6/1998	Shirai et al.
4,039,215	A	8/1977	Minhinnick	5,775,860	A	7/1998	Meyer
4,042,307	A	8/1977	Jarvis	5,795,118	A	8/1998	Osada et al.
4,043,585	A	8/1977	Yamanaka	5,797,170	A	8/1998	Akeno
4,158,511	A	6/1979	Herbenar	5,797,714	A	8/1998	Oddenino
4,169,297	A	10/1979	Weihrauch	5,803,646	A	9/1998	Weihrauch
4,193,588	A	3/1980	Doneaux	5,806,915	A	9/1998	Takabatake
4,213,675	A	7/1980	Pilhall	5,810,535	A	9/1998	Fleckenstein et al.
4,237,573	A	12/1980	Weihrauch	5,820,292	A	10/1998	Fremstad
4,300,851	A	11/1981	Thelander	5,846,631	A	12/1998	Nowosiadly
4,313,609	A	2/1982	Clements	5,934,729	A	8/1999	Baack
4,318,208	A	3/1982	Borja	5,941,673	A	8/1999	Hayakawa et al.
4,325,574	A	4/1982	Umemoto et al.	6,073,315	A	6/2000	Rasmussen
4,363,839	A	12/1982	Watanabe et al.	6,079,083	A	6/2000	Akashi
4,364,150	A	12/1982	Remington	6,095,594	A	8/2000	Riddle et al.
4,384,803	A	5/1983	Cachia	6,103,987	A	8/2000	Nordquist
				6,109,882	A	8/2000	Popov
				6,152,436	A	11/2000	Sonderegger et al.
				6,164,603	A	12/2000	Kawai
				6,193,430	B1	2/2001	Culpepper et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,199,248 B1	3/2001	Akashi	7,557,051 B2	7/2009	Ryu et al.
6,202,962 B1	3/2001	Snyder	7,568,316 B2	8/2009	Choby et al.
6,209,175 B1	4/2001	Gershenson	7,591,573 B2	9/2009	Maliar et al.
6,209,178 B1	4/2001	Wiese et al.	D602,349 S	10/2009	Andersson
6,254,304 B1	7/2001	Takizawa et al.	7,614,836 B2	11/2009	Mohiuddin
6,264,869 B1	7/2001	Notarpietro et al.	7,672,126 B2	3/2010	Yeh
6,299,478 B1	10/2001	Jones et al.	7,677,650 B2	3/2010	Huttenlocher
6,321,495 B1	11/2001	Oami	7,727,667 B2	6/2010	Sakurai
6,336,767 B1	1/2002	Nordquist et al.	7,764,853 B2	7/2010	Yi et al.
6,345,420 B1	2/2002	Nabeshima	7,793,998 B2	9/2010	Matsui et al.
6,349,904 B1	2/2002	Polad	7,802,831 B2	9/2010	Isayama et al.
6,351,380 B1	2/2002	Curlee	7,828,372 B2	11/2010	Ellison
6,354,815 B1	3/2002	Svihla et al.	7,862,272 B2	1/2011	Nakajima
6,378,931 B1	4/2002	Kolluri et al.	7,869,003 B2	1/2011	Van Doren et al.
6,398,449 B1	6/2002	Loh	7,883,137 B2	2/2011	Bar
6,484,370 B2	11/2002	Kanie et al.	7,922,415 B2	4/2011	Rudduck et al.
6,485,241 B1	11/2002	Oxford	7,946,684 B2	5/2011	Drury et al.
6,523,229 B2	2/2003	Severson	8,029,222 B2	10/2011	Nitsche
6,523,817 B1	2/2003	Landry, Jr.	8,061,861 B2	11/2011	Paxton et al.
6,533,391 B1	3/2003	Pan	8,101,264 B2	1/2012	Pace et al.
6,543,979 B2	4/2003	Iwatsuki	8,136,819 B2	3/2012	Yoshitsune et al.
6,557,260 B1	5/2003	Morris	8,162,375 B2	4/2012	Gurtatowski et al.
6,568,701 B1	5/2003	Burdack et al.	8,203,496 B2	6/2012	Miller et al.
6,579,397 B1	6/2003	Spain et al.	8,203,843 B2	6/2012	Chen
6,591,801 B1	7/2003	Fonville	8,228,640 B2	7/2012	Woodhead et al.
6,609,717 B2	8/2003	Hinson	8,249,679 B2	8/2012	Cui
6,637,095 B2	10/2003	Stumpf et al.	8,261,581 B2	9/2012	Cerruti et al.
6,658,698 B2	12/2003	Chen	8,276,961 B2	10/2012	Kwolek
6,662,411 B2	12/2003	Rubenstein	8,291,553 B2	10/2012	Moberg
6,664,470 B2	12/2003	Nagamoto	8,297,137 B2	10/2012	Dole
6,677,065 B2	1/2004	Blauer	8,297,661 B2	10/2012	Proulx et al.
6,692,016 B2	2/2004	Yokota	8,312,887 B2	11/2012	Dunn et al.
6,712,329 B2	3/2004	Ishigami et al.	8,371,788 B2	2/2013	Lange
6,746,172 B2	6/2004	Culpepper	8,414,048 B1	4/2013	Kwolek
6,757,942 B2	7/2004	Matsui	8,444,199 B2	5/2013	Takeuchi et al.
6,799,758 B2	10/2004	Fries	8,572,818 B2	11/2013	Hofmann
6,821,091 B2	11/2004	Lee	8,619,504 B2	12/2013	Wyssbrod
6,840,969 B2	1/2005	Kobayashi et al.	8,677,573 B2	3/2014	Lee
6,857,676 B2	2/2005	Kawaguchi et al.	8,695,201 B2	4/2014	Morris
6,857,809 B2	2/2005	Granata	8,720,016 B2	5/2014	Beaulieu
6,908,117 B1	6/2005	Pickett, Jr. et al.	8,726,473 B2	5/2014	Dole
6,932,416 B2	8/2005	Clauson	8,746,801 B2	6/2014	Nakata
6,948,753 B2	9/2005	Yoshida et al.	8,826,499 B2	9/2014	Tempesta
6,951,349 B2	10/2005	Yokota	8,833,771 B2	9/2014	Lesnau
6,959,954 B2	11/2005	Brandt et al.	8,833,832 B2	9/2014	Whipps
6,966,601 B2	11/2005	Matsumoto et al.	8,834,058 B2	9/2014	Woicke
6,971,831 B2	12/2005	Fattori et al.	8,905,812 B2	12/2014	Pai-Chen
6,997,487 B2	2/2006	Kitzis	8,910,350 B2	12/2014	Poulakis
7,000,941 B2	2/2006	Yokota	9,003,891 B2	4/2015	Frank
7,008,003 B1	3/2006	Hirose et al.	9,039,318 B2	5/2015	Mantei et al.
7,014,094 B2	3/2006	Alcoe	9,050,690 B2	6/2015	Hammer et al.
7,017,239 B2	3/2006	Kurily et al.	9,061,715 B2	6/2015	Morris
7,036,779 B2	5/2006	Kawaguchi et al.	9,062,991 B2	6/2015	Kanagaraj
7,055,785 B1	6/2006	Diggie, III	9,067,625 B2	6/2015	Morris
7,055,849 B2	6/2006	Yokota	2001/0030414 A1	10/2001	Yokota
7,059,628 B2	6/2006	Yokota	2001/0045757 A1	11/2001	Hideki et al.
7,073,260 B2	7/2006	Jensen	2002/0045086 A1	4/2002	Tsuji et al.
7,089,998 B2	8/2006	Crook	2002/0060275 A1	5/2002	Polad
7,097,198 B2	8/2006	Yokota	2002/0092598 A1	7/2002	Jones et al.
7,121,611 B2	10/2006	Hirotani et al.	2002/0136617 A1	9/2002	Imahigashi
7,144,183 B2	12/2006	Lian et al.	2003/0007831 A1	1/2003	Lian et al.
7,172,210 B2	2/2007	Yokota	2003/0059255 A1	3/2003	Kirchen
7,178,855 B2	2/2007	Catron et al.	2003/0080131 A1	5/2003	Fukuo
7,198,315 B2	4/2007	Cass et al.	2003/0082986 A1	5/2003	Wiens et al.
7,234,852 B2	6/2007	Nishizawa et al.	2003/0087047 A1	5/2003	Blauer
7,306,418 B2	12/2007	Kornblum	2003/0108401 A1	6/2003	Agha et al.
7,322,500 B2	1/2008	Maierholzner	2003/0180122 A1	9/2003	Dobson
7,344,056 B2	3/2008	Shelmon et al.	2004/0028503 A1	2/2004	Charles
7,360,964 B2	4/2008	Tsuya	2004/0037637 A1	2/2004	Lian et al.
7,369,408 B2	5/2008	Chang	2004/0131896 A1	7/2004	Blauer
7,435,031 B2	10/2008	Granata	2004/0139678 A1	7/2004	Pervan
7,454,105 B2	11/2008	Yi	2004/0140651 A1	7/2004	Yokota
7,487,884 B2	2/2009	Kim	2004/0208728 A1	10/2004	Fattori et al.
7,493,716 B2	2/2009	Brown	2004/0262873 A1	12/2004	Wolf et al.
7,547,061 B2	6/2009	Horimatsu	2005/0016116 A1	1/2005	Scherff
			2005/0031946 A1	2/2005	Kruger et al.
			2005/0054229 A1	3/2005	Tsuya
			2005/0082449 A1	4/2005	Kawaguchi et al.
			2005/0109489 A1	5/2005	Kobayashi

(56)

References Cited

U.S. PATENT DOCUMENTS

2005/0156409	A1	7/2005	Yokota	2012/0073094	A1	3/2012	Bishop
2005/0156410	A1	7/2005	Yokota	2012/0112489	A1	5/2012	Okimoto
2005/0156416	A1	7/2005	Yokota	2012/0115010	A1	5/2012	Smith et al.
2005/0244250	A1	11/2005	Okada et al.	2012/0240363	A1	9/2012	Lee
2006/0092653	A1	5/2006	Tachiiwa et al.	2012/0251226	A1	10/2012	Liu et al.
2006/0102214	A1	5/2006	Clemons	2012/0261951	A1	10/2012	Mildner et al.
2006/0110109	A1	5/2006	Yi et al.	2012/0301067	A1	11/2012	Morgan
2006/0113755	A1	6/2006	Yokota	2012/0311829	A1	12/2012	Dickinson
2006/0125286	A1	6/2006	Horimatsu et al.	2012/0321379	A1	12/2012	Wang et al.
2006/0141318	A1	6/2006	MacKinnon et al.	2013/0019454	A1	1/2013	Colombo et al.
2006/0163902	A1	7/2006	Engel	2013/0019455	A1	1/2013	Morris
2006/0170242	A1	8/2006	Forrester et al.	2013/0027852	A1	1/2013	Wang
2006/0197356	A1	9/2006	Catron et al.	2013/0055822	A1	3/2013	Frank
2006/0202449	A1	9/2006	Yokota	2013/0071181	A1	3/2013	Herzinger et al.
2006/0237995	A1	10/2006	Huttenlocher	2013/0157015	A1	6/2013	Morris
2006/0249520	A1	11/2006	DeMonte	2013/0212858	A1	8/2013	Herzinger et al.
2006/0264076	A1	11/2006	Chen	2013/0269873	A1	10/2013	Herzinger et al.
2007/0034636	A1	2/2007	Fukuo	2013/0287992	A1	10/2013	Morris
2007/0040411	A1	2/2007	Dauvergne	2014/0033493	A1	2/2014	Morris et al.
2007/0113483	A1	5/2007	Hernandez	2014/0041176	A1	2/2014	Morris
2007/0113485	A1	5/2007	Hernandez	2014/0041185	A1	2/2014	Morris et al.
2007/0126211	A1	6/2007	Moerke et al.	2014/0041199	A1	2/2014	Morris
2007/0137018	A1	6/2007	Aigner et al.	2014/0042704	A1	2/2014	Polewarczyk
2007/0144659	A1	6/2007	De La Fuente	2014/0047691	A1	2/2014	Colombo et al.
2007/0205627	A1	9/2007	Ishiguro	2014/0047697	A1	2/2014	Morris
2007/0227942	A1	10/2007	Hirano	2014/0080036	A1	3/2014	Smith et al.
2007/0251055	A1	11/2007	Gerner	2014/0132023	A1	5/2014	Watanabe
2007/0274777	A1	11/2007	Winkler	2014/0175774	A1	6/2014	Kansteiner
2007/0292205	A1	12/2007	Duval	2014/0202628	A1	7/2014	Sreetharan et al.
2008/0014508	A1	1/2008	Van Doren et al.	2014/0208561	A1	7/2014	Colombo et al.
2008/0018128	A1	1/2008	Yamagiwa et al.	2014/0208572	A1	7/2014	Colombo et al.
2008/0073888	A1	3/2008	Enriquez	2014/0264206	A1	9/2014	Morris
2008/0094447	A1	4/2008	Drury et al.	2014/0292013	A1	10/2014	Colombo et al.
2008/0128346	A1	6/2008	Bowers	2014/0298638	A1	10/2014	Colombo et al.
2008/0217796	A1	9/2008	Van Bruggen et al.	2014/0298640	A1	10/2014	Morris et al.
2008/0260488	A1	10/2008	Scroggie et al.	2014/0298962	A1	10/2014	Morris et al.
2009/0028506	A1	1/2009	Yi et al.	2014/0300130	A1	10/2014	Morris et al.
2009/0072591	A1	3/2009	Baumgartner	2014/0301103	A1	10/2014	Colombo et al.
2009/0091156	A1	4/2009	Neubrand	2014/0301777	A1	10/2014	Morris et al.
2009/0093111	A1	4/2009	Buchwalter et al.	2014/0301778	A1	10/2014	Morris et al.
2009/0126168	A1	5/2009	Kobe et al.	2014/0360824	A1	12/2014	Morris et al.
2009/0134652	A1	5/2009	Araki	2014/0360826	A1	12/2014	Morris et al.
2009/0141449	A1	6/2009	Yeh	2014/0366326	A1	12/2014	Colombo et al.
2009/0174207	A1	7/2009	Lota	2014/0369742	A1	12/2014	Morris et al.
2009/0243172	A1	10/2009	Ting et al.	2014/0369743	A1	12/2014	Morris et al.
2009/0265896	A1	10/2009	Beak	2015/0016864	A1	1/2015	Morris et al.
2009/0309388	A1	12/2009	Ellison	2015/0016918	A1	1/2015	Colombo
2010/0001539	A1	1/2010	Kikuchi et al.	2015/0069779	A1	3/2015	Morris et al.
2010/0021267	A1	1/2010	Nitsche	2015/0274217	A1	10/2015	Colombo
2010/0061045	A1	3/2010	Chen	2015/0291222	A1	10/2015	Colombo et al.
2010/0102538	A1	4/2010	Paxton et al.				
2010/0134128	A1	6/2010	Hobbs				
2010/0147355	A1	6/2010	Shimizu et al.				
2010/0232171	A1	9/2010	Cannon				
2010/0247034	A1	9/2010	Yi et al.				
2010/0263417	A1	10/2010	Shoenow				
2010/0270745	A1	10/2010	Hurlbert et al.				
2010/0307848	A1	12/2010	Hashimoto				
2011/0012378	A1	1/2011	Ueno et al.				
2011/0036542	A1	2/2011	Woicke				
2011/0076588	A1	3/2011	Yamaura				
2011/0083392	A1	4/2011	Timko				
2011/0103884	A1	5/2011	Shiomoto et al.				
2011/0119875	A1	5/2011	Iwasaki				
2011/0131918	A1	6/2011	Glynn				
2011/0154645	A1	6/2011	Morgan				
2011/0175376	A1	7/2011	Whitens et al.				
2011/0183152	A1	7/2011	Lanham				
2011/0191990	A1	8/2011	Beaulieu				
2011/0207024	A1	8/2011	Bogumil et al.				
2011/0239418	A1	10/2011	Huang				
2011/0296764	A1	12/2011	Sawatani et al.				
2011/0311332	A1	12/2011	Ishman				
2012/0000291	A1	1/2012	Christoph				
2012/0020726	A1	1/2012	Jan				

FOREIGN PATENT DOCUMENTS

CN	1205285	A	1/1999
CN	1328521	A	12/2001
CN	1426872	A	7/2003
CN	1670986	A	9/2005
CN	100573975	C	9/2005
CN	1693721	A	11/2005
CN	1771399	A	5/2006
CN	1774580	A	5/2006
CN	1933747	A	3/2007
CN	2888807	Y	4/2007
CN	1961157	A	5/2007
CN	2915389		6/2007
CN	101250964	A	4/2008
CN	201259846	Y	6/2009
CN	201268336	Y	7/2009
CN	201310827	Y	9/2009
CN	201540513	U	8/2010
CN	101821534		9/2010
CN	101930253	A	12/2010
CN	201703439	U	1/2011
CN	201737062	U	2/2011
CN	201792722	U	4/2011
CN	201818606	U	5/2011
CN	201890285	U	7/2011
CN	102144102	A	8/2011
CN	102235402	A	11/2011

(56)

References Cited

FOREIGN PATENT DOCUMENTS

CN	202079532	U	12/2011
CN	102313952	A	1/2012
CN	202132326	U	2/2012
CN	102756633		10/2012
CN	102803753	A	11/2012
CN	102869891	A	1/2013
CN	202686206	U	1/2013
CN	102939022	A	2/2013
CN	202987018	U	6/2013
CN	103201525	A	7/2013
DE	1220673	B	7/1966
DE	3704190	A1	12/1987
DE	3711696	A1	10/1988
DE	3805693	A1	2/1989
DE	69600357	T2	12/1998
DE	10234253	B3	4/2004
DE	102008005618	A1	7/2009
DE	102008047464	A1	4/2010
DE	102010028323	A1	11/2011
DE	102011050003	A1	10/2012
DE	102012212101	B3	7/2013
EP	0118796		9/1984
EP	1132263	A1	9/2001
EP	1243471	A2	9/2002
EP	1273766	A1	1/2003
EP	1293384	A2	3/2003
EP	1384536	A2	1/2004
EP	1388449	A1	2/2004
EP	1452745	A1	9/2004
EP	2166235	A2	3/2010
EP	2450259	A1	5/2012
EP	2458454	A1	5/2012
FR	1369198	A	8/1964
FR	2009941	A1	2/1970
JP	2000010514	A	1/2000
JP	2001141154	A	5/2001
JP	2001171554	A	6/2001
JP	2005268004		9/2005
JP	2006205918		8/2006
JP	2008307938	A	12/2008
JP	2009084844		4/2009
JP	2009187789	A	8/2009
JP	2011085174	A	4/2011
JP	2012060791	A	3/2012
JP	2012112533	A	6/2012
KR	20030000251	A1	1/2003
WO	0055517	A2	3/2000
WO	0132454	A3	11/2001
WO	2004010011		1/2004
WO	2008140659	A1	11/2008
WO	2010105354	A1	9/2010
WO	2011025606		3/2011
WO	2013088447	A1	6/2013
WO	2013191622	A1	12/2013

OTHER PUBLICATIONS

"An Anti Backlash Two-Part Shaft Coupling With Interlocking Elastically Averaged Teeth" by Mahadevan Balasubramaniam, Edmund Golaski, Seung-Kil Son, Krishnan Sriram, and Alexander Slocum, Precision Engineering, V. 26, No. 3, Elsevier Publishing, Jul. 2002.

"The Design of High Precision Parallel Mechanisms Using Binary Actuation and Elastic Averaging: With Application to MRI Cancer Treatment" by L.M. Devita, J.S. Plante, and S. Dubowsky, 12th IFToMM World Congress (France), Jun. 2007.

"Passive Alignment of Micro-Fluidic Chips Using the Principle of Elastic Averaging" by Sitanshu Gurung, Thesis, Louisiana State University, Dept. of Mechanical Engineering, Dec. 2007.

"Precision Connector Assembly Using Elastic Averaging" by Patrick J. Willoughby and Alexander H. Slocum, Massachusetts Institute of Technology (MIT), Cambridge, MA, American Society for Precision Engineering, 2004.

U.S. Appl. No. 13/752,449, filed Jan. 29, 2013, entitled "Elastic Insert Alignment Assembly and Method of Reducing Positional Variation", inventors: Steven E. Morris and Michael D. Richardson.

U.S. Appl. No. 13/755,759, filed Jan. 31, 2013, entitled "Elastic Alignment Assembly for Aligning Mated Components and Method of Reducing Positional Variation", inventors: Joel Colombo, Michael D. Richardson, and Steven E. Morris.

U.S. Appl. No. 13/851,222, filed Mar. 27, 2013, entitled "Elastically Averaged Alignment System", inventors: Joel Colombo and Steven E. Morris.

U.S. Appl. No. 13/855,928, filed Apr. 3, 2013, entitled "Elastic Averaging Alignment System, Method of Making the Same and Cutting Punch Therefor", inventors: Steven E. Morris, Jennifer P. Lawall, Joel Colombo, and Jeffrey L. Konchan.

U.S. Appl. No. 13/856,888, filed Apr. 4, 2013, entitled "Elastic Retaining Assembly for Matable Components and Method of Assembling", inventors: Steven E. Morris, Jennifer P. Lawall, Joel Colombo, and Toure D. Lee.

U.S. Appl. No. 13/856,927, filed Apr. 4, 2013, entitled "Elastic Tubular Attachment Assembly for Mating Components and Method of Mating Components", inventors: Steven E. Morris and Jennifer P. Lawall.

U.S. Appl. No. 13/856,956, filed Apr. 4, 2013, entitled "Elastic Clip Retaining Arrangement and Method of Mating Structures with an Elastic Clip Retaining Arrangement", inventors: Joel Colombo, Steven E. Morris and Jeffrey L. Konchan.

U.S. Appl. No. 13/856,973, filed Apr. 4, 2013, entitled "Elastically Deformable Flange Locator Arrangement and Method of Reducing Positional Variation", inventors: Joel Colombo, Steven E. Morris and Michael D. Richardson.

U.S. Appl. No. 13/858,478, filed Apr. 8, 2013, entitled "Elastic Mating Assembly and Method of Elastically Assembling Matable Components", inventors: Steven E. Morris and Jennifer P. Lawall.

U.S. Appl. No. 13/859,109, filed Apr. 9, 2013, entitled "Elastic Retaining Arrangement for Jointed Components and Method of Reducing a Gap Between Jointed Components," inventors: Steven E. Morris, James M. Kushner, Victoria L. Enyedy, Jennifer P. Lawall, and Piotr J. Ogonek.

U.S. Appl. No. 13/915,132, filed Jun. 11, 2013, entitled "Elastically Deformable Energy Management Arrangement and Method of Managing Energy Absorption," inventors: Steven E. Morris, Randy A. Johnson and Jennifer P. Lawall.

U.S. Appl. No. 13/915,177, filed Jun. 11, 2013, entitled "Elastically Deformable Energy Management Assembly and Method of Managing Energy Absorption," inventors: Steven E. Morris, Jennifer P. Lawall, and Randy Johnson.

U.S. Appl. No. 13/917,005, filed Jun. 13, 2013, entitled "Elastic Attachment Assembly and Method of Reducing Positional Variation and Increasing Stiffness," inventors: Steven E. Morris and Jennifer P. Lawall.

U.S. Appl. No. 13/917,074, filed Jun. 13, 2013, entitled "Elastically Deformable Retaining Hook for Components to be Mated Together and Method of Assembling", inventors: Joel Colombo, Jeffrey L. Konchan, Steven E. Morris, and Steve J. Briggs.

U.S. Appl. No. 13/918,183, filed Jun. 14, 2013, entitled "Elastic Retaining Assembly for Matable Components and Method of Assembling," inventors: Steven E. Morris and Jennifer P. Lawall.

U.S. Appl. No. 13/939,503, filed on Jul. 11, 2013, entitled "Elastically Averaged Alignment Systems and Methods," inventor: Joel Colombo.

U.S. Appl. No. 13/940,912, filed Jul. 12, 2013, entitled "Alignment Arrangement for Mated Components and Method", inventors: Steven E. Morris and Jennifer P. Lawall.

Cross-sectional view of a prior art infrared welded assembly of BMW, Munich, Germany. Believed on the market since about Jan. 1, 2010.

"Coupling Types—Elastic Averaging." MIT. Aug. 3, 2012, [online], [retrieved on Nov. 12, 2014]. Retrieved from the Internet <URL:https://web.archive.org/web/20120308055935/http://pergatory.mit.edu/kinematiccouplings/html/about/elastic_averaging.html>.

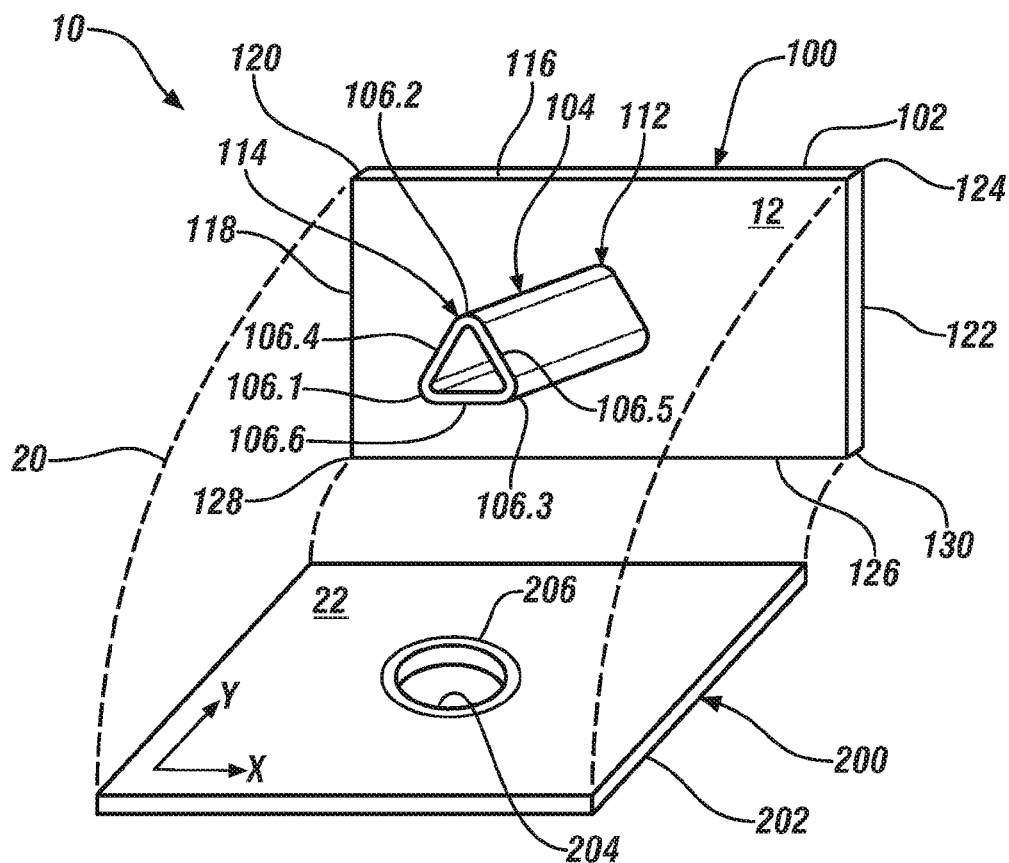


FIG. 1

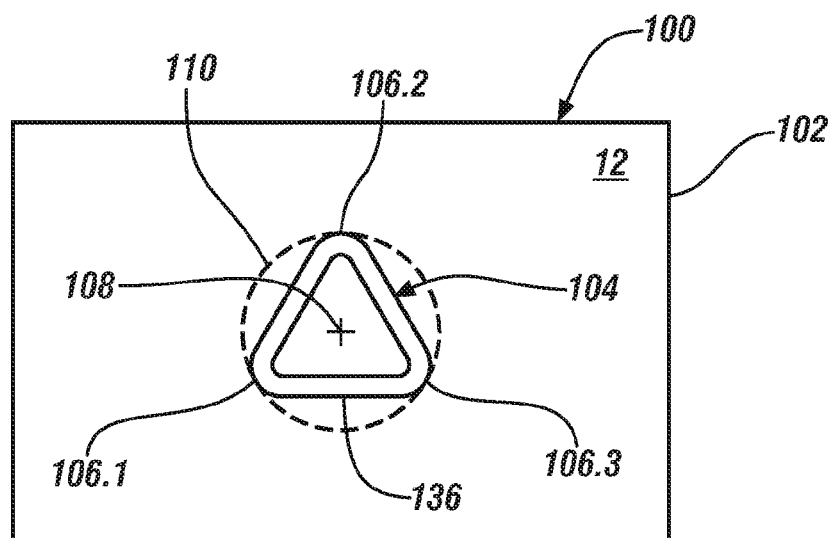


FIG. 2

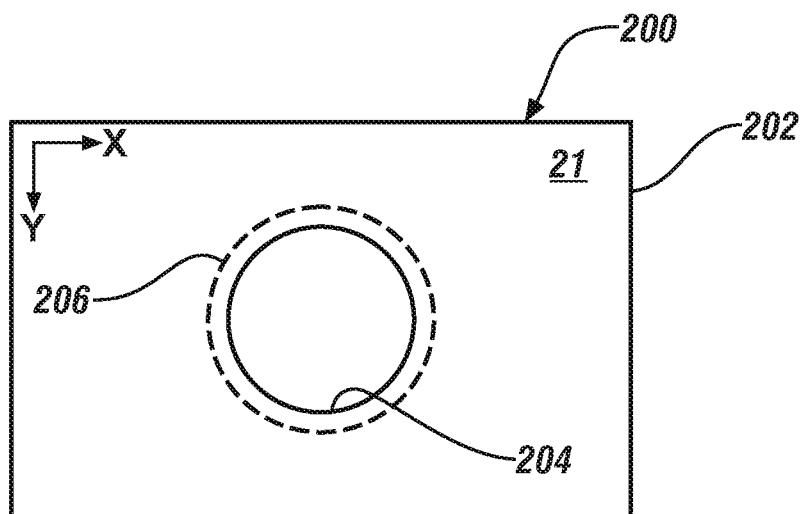


FIG. 3

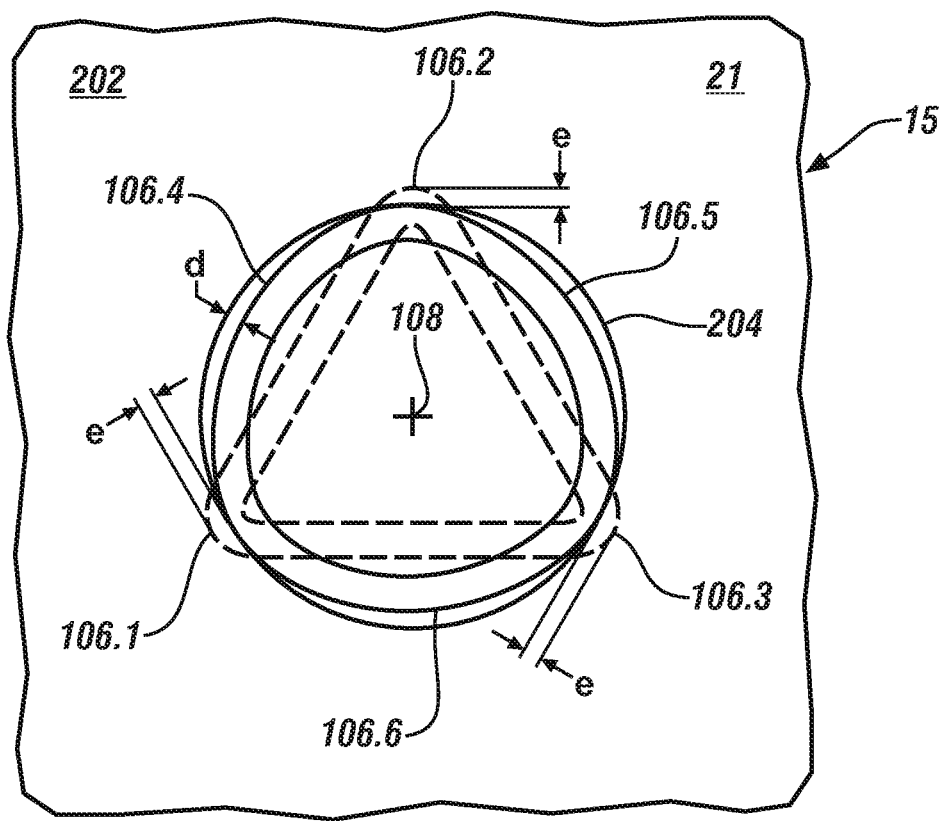


FIG. 4

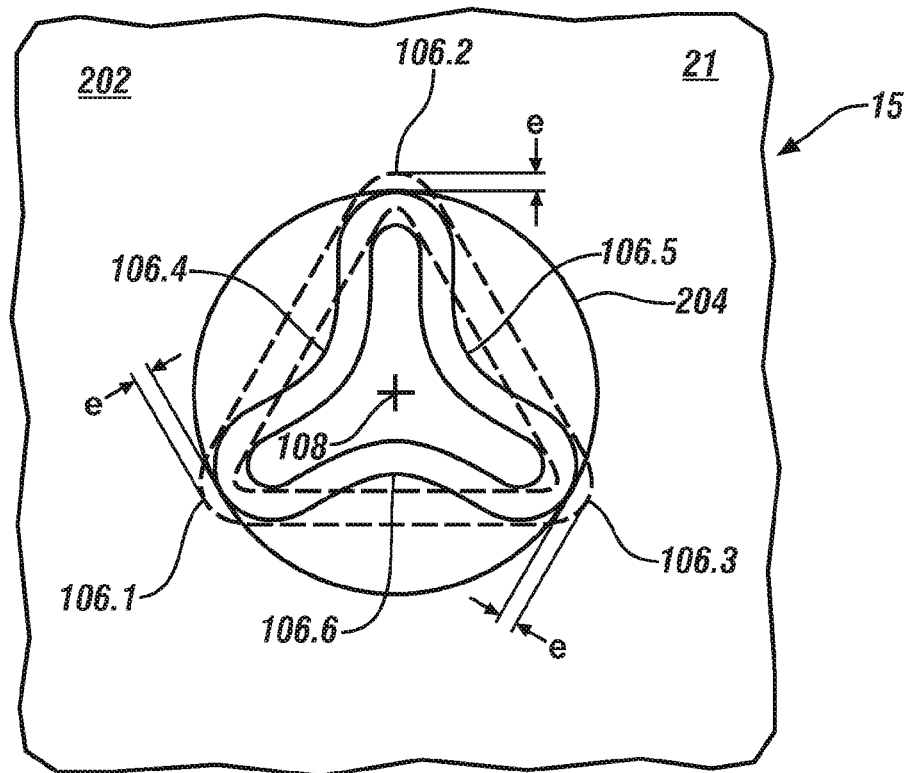


FIG. 5

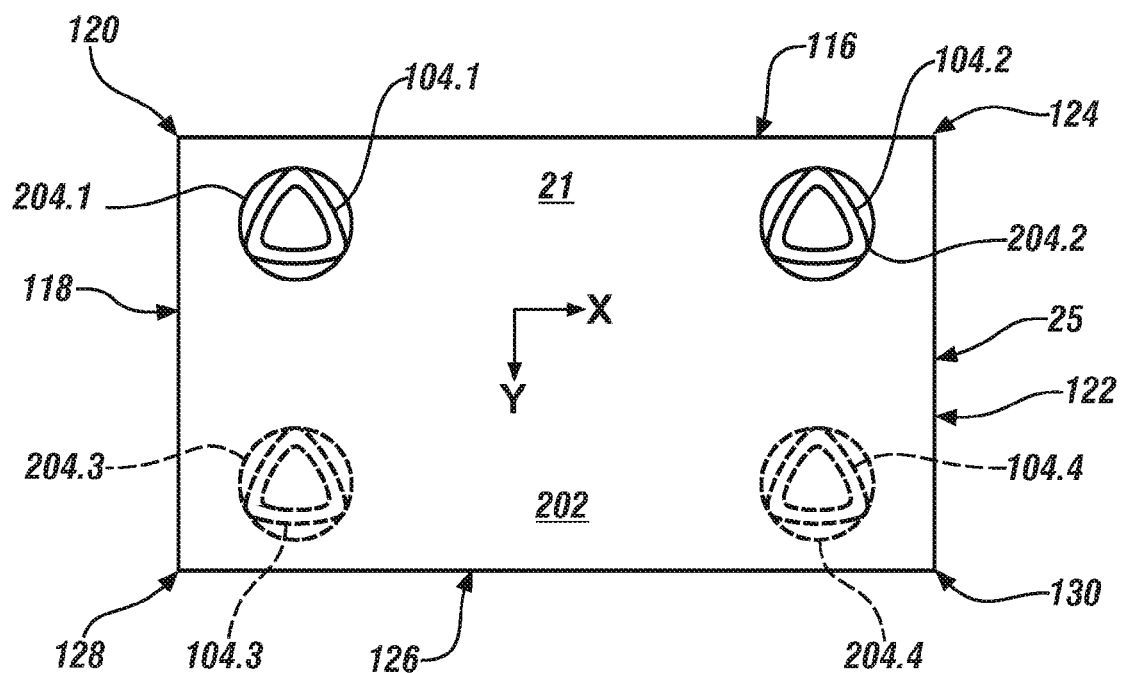


FIG. 6

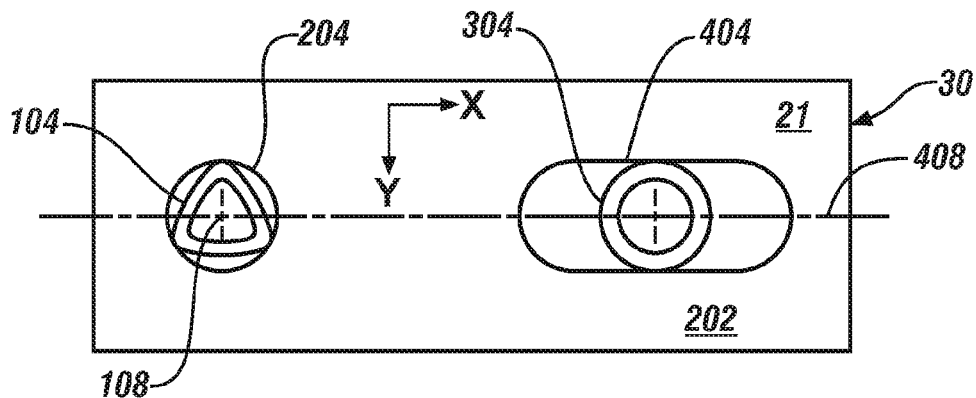


FIG. 7

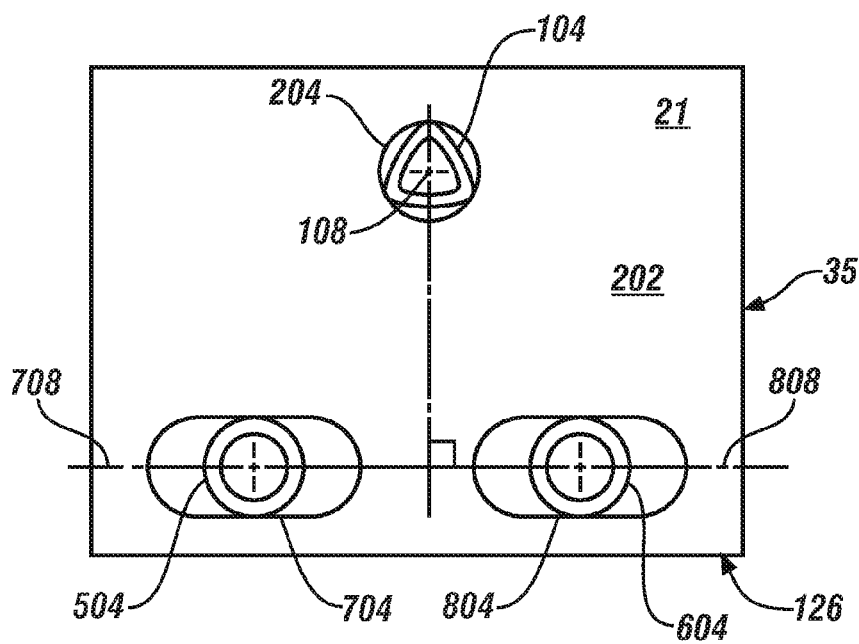


FIG. 8

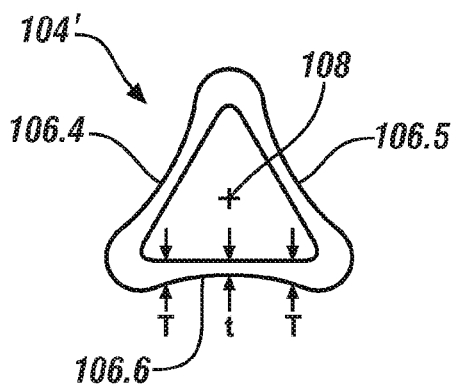


FIG. 9

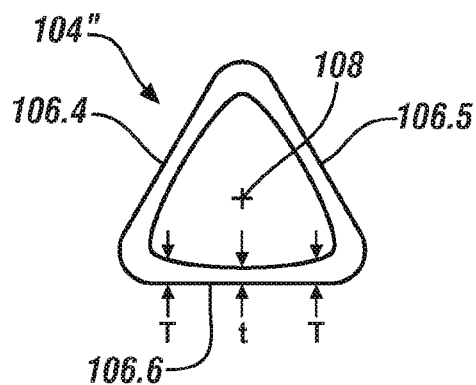


FIG. 10

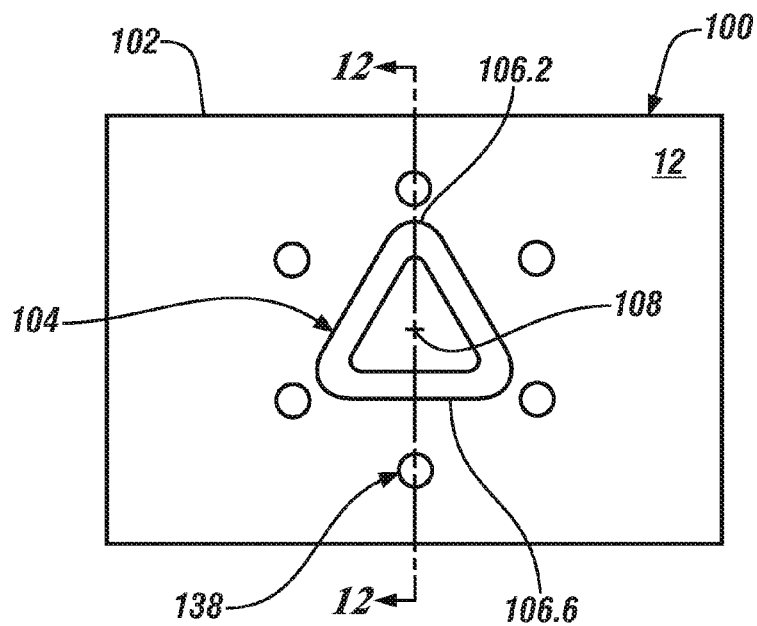


FIG. 11

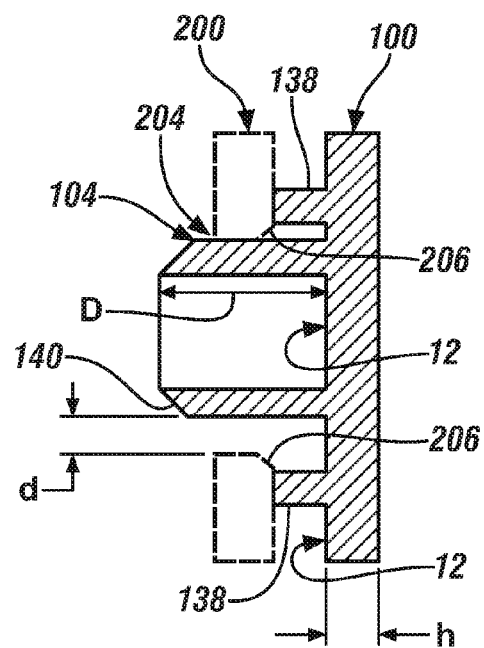


FIG. 12

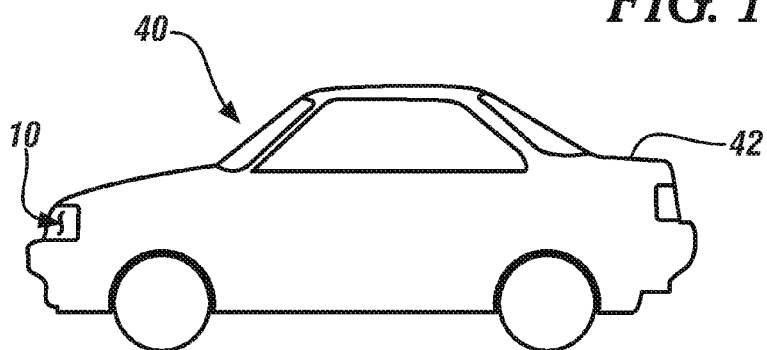


FIG. 13

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LOBULAR ELASTIC TUBE ALIGNMENT SYSTEM FOR PROVIDING PRECISE FOUR-WAY ALIGNMENT OF COMPONENTS

FIELD OF THE INVENTION

The subject invention relates to the art of alignment systems, more particularly to an elastically averaged alignment system, and even more particularly to an elastically averaged alignment system providing four-way alignment of mating components on which the alignment system is incorporated.

BACKGROUND

Currently, components, particularly vehicular components such as those found in automotive vehicles, which are to be mated together in a manufacturing process are mutually located with respect to each other by alignment features that are oversized and/or undersized to provide spacing to freely move the components relative to one another to align them without creating an interference therebetween that would hinder the manufacturing process. One example includes two-way and/or four-way male alignment features, typically upstanding bosses, which are received into corresponding female alignment features, typically apertures in the form of holes or slots. There is a clearance between the male alignment features and their respective female alignment features which is predetermined to match anticipated size and positional variation tolerances of the male and female alignment features as a result of manufacturing (or fabrication) variances. As a result, significant positional variation can occur between the mated first and second components having the aforementioned alignment features, which may contribute to the presence of undesirably large variation in their alignment, particularly with regard to the gaps and spacing between them. In the case where these misaligned components are also part of another assembly, such misalignments can also affect the function and/or aesthetic appearance of the entire assembly. Regardless of whether such misalignment is limited to two components or an entire assembly, it can negatively affect function and result in a perception of poor quality.

Accordingly, the art of alignment systems can be enhanced by providing a precise or fine positioning and alignment system or mechanism that can ensure precise four-way alignment of two components via elastic averaging of a single elastically deformable alignment element disposed in mating engagement with a corresponding single alignment feature.

SUMMARY OF THE INVENTION

An exemplary embodiment of the invention includes an elastically averaged alignment system having a first component and a second component. The first component includes a first alignment member and an elastically deformable alignment element fixedly disposed with respect to the first alignment member. The second component includes a second alignment member and an alignment feature fixedly disposed with respect to the second alignment member. The elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the alignment feature. The elastically deformable alignment element includes a lobular hollow tube having a cross-section having at least three outwardly oriented lobes relative to a central axis of the hollow tube, and the alignment feature includes a circular aperture. Portions of the elastically deformable alignment element when inserted into the alignment feature elastically deform to an elastically averaged final configuration

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that aligns the first alignment member with the second alignment member in four planar orthogonal directions.

Another exemplary embodiment of the invention includes a vehicle having a body and an elastically averaged alignment system integrally arranged with the body. The elastically averaged alignment system includes a first component and a second component. The first component includes a first alignment member and an elastically deformable alignment element fixedly disposed with respect to the first alignment member. The second component includes a second alignment member and an alignment feature fixedly disposed with respect to the second alignment member. The elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the alignment feature. The elastically deformable alignment element includes a lobular hollow tube having a cross-section having at least three outwardly oriented lobes relative to a central axis of the hollow tube, and the alignment feature includes a circular aperture. Portions of the elastically deformable alignment element when inserted into the alignment feature elastically deform to an elastically averaged final configuration that aligns the first alignment member with the second alignment member in four planar orthogonal directions.

The above features and advantages and other features and advantages of the invention are readily apparent from the following detailed description of the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, advantages and details appear, by way of example only, in the following detailed description of embodiments, the detailed description referring to the drawings in which:

FIG. 1 depicts an elastically averaging alignment system in accordance with an embodiment of the invention;

FIG. 2 depicts a front plan view of a first component of the elastically averaging alignment system of FIG. 1;

FIG. 3 depicts a rear plan view of a second component of the elastically averaging alignment system of FIG. 1;

FIG. 4 depicts a partial rear plan view of first and second components of the elastically averaging alignment system of FIG. 1 in a mating arrangement, in accordance with an embodiment of the invention;

FIG. 5 depicts a partial rear plan view, alternative to that of FIG. 4, of first and second components of the elastically averaging alignment system of FIG. 1 in a mating arrangement, in accordance with an embodiment of the invention;

FIG. 6 depicts a rear plan view of an elastically averaging alignment system having additional elastically averaging features that are combinable with the elastically averaging features depicted in FIG. 1, in accordance with an embodiment of the invention;

FIG. 7 depicts a rear plan view of another elastically averaging alignment system having additional elastically averaging features that are combinable with the elastically averaging features depicted in FIG. 1, in accordance with an embodiment of the invention;

FIG. 8 depicts a rear plan view of yet another elastically averaging alignment system having additional elastically averaging features that are combinable with the elastically averaging features depicted in FIG. 1, in accordance with an embodiment of the invention;

FIG. 9 depicts a front plan view of a tri-lobular elastically deformable alignment element in accordance with an embodiment of the invention;

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FIG. 10 depicts a front plan view of another tri-lobular elastically deformable alignment element in accordance with an embodiment of the invention;

FIG. 11 depicts an alternative front plan view of the first component similar to that of FIG. 1, but with integrally formed standoffs, in accordance with an embodiment of the invention;

FIG. 12 depicts a section cut through FIG. 11 along cut line 12-12, in accordance with an embodiment of the invention; and

FIG. 13 depicts a vehicle having the elastically averaging alignment system of FIG. 1, in accordance with an embodiment of the invention.

DESCRIPTION OF THE EMBODIMENTS

The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. For example, the embodiments shown are applicable to vehicle body panels, but the alignment system disclosed herein may be used with any suitable components to provide elastic averaging for precision location and alignment of all manner of mating components and component applications, including many industrial, consumer product (e.g., consumer electronics, various appliances and the like), transportation, energy and aerospace applications, and particularly including many other types of vehicular components and applications, such as various interior, exterior and under hood vehicular components and applications. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

As used herein, the term “elastically deformable” refers to components, or portions of components, including component features, comprising materials having a generally elastic deformation characteristic, wherein the material is configured to undergo a resiliently reversible change in its shape, size, or both, in response to application of a force. The force causing the resiliently reversible or elastic deformation of the material may include a tensile, compressive, shear, bending or torsional force, or various combinations of these forces. The elastically deformable materials may exhibit linear elastic deformation, for example that described according to Hooke’s law, or non-linear elastic deformation.

Elastic averaging provides elastic deformation of the interface(s) between mated components, wherein the average deformation provides a precise alignment, the manufacturing positional variance being minimized to X_{min} , defined by $X_{min}=X/\sqrt{N}$, wherein X is the manufacturing positional variance of the locating features of the mated components and N is the number of features inserted. To obtain elastic averaging, an elastically deformable component is configured to have at least one feature and its contact surface(s) that is over-constrained and provides an interference fit with a mating feature of another component and its contact surface(s). The over-constrained condition and interference fit resiliently reversibly (elastically) deforms at least one of the at least one feature or the mating feature, or both features. The resiliently reversible nature of these features of the components allows repeatable insertion and withdrawal of the components that facilitates their assembly and disassembly. Positional variance of the components may result in varying forces being applied over regions of the contact surfaces that are over-constrained and engaged during insertion of the component in an interference condition. It is to be appreciated that a single inserted component may be elastically averaged with respect to a length of the perimeter of the component. The principles

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of elastic averaging are described in detail in commonly owned, co-pending U.S. patent application Ser. No. 13/187,675, the disclosure of which is incorporated by reference herein in its entirety. The embodiments disclosed above provide the ability to convert an existing component that is not compatible with the above-described elastic averaging principles, or that would be further aided with the inclusion of a four-way elastic averaging system as herein disclosed, to an assembly that does facilitate elastic averaging and the benefits associated therewith.

Any suitable elastically deformable material may be used for the mating components and alignment features disclosed herein and discussed further below, particularly those materials that are elastically deformable when formed into the features described herein. This includes various metals, polymers, ceramics, inorganic materials or glasses, or composites of any of the aforementioned materials, or any other combinations thereof suitable for a purpose disclosed herein. Many composite materials are envisioned, including various filled polymers, including glass, ceramic, metal and inorganic material filled polymers, particularly glass, metal, ceramic, inorganic or carbon fiber filled polymers. Any suitable filler morphology may be employed, including all shapes and sizes of particulates or fibers. More particularly any suitable type of fiber may be used, including continuous and discontinuous fibers, woven and unwoven cloths, felts or tows, or a combination thereof. Any suitable metal may be used, including various grades and alloys of steel, cast iron, aluminum, magnesium or titanium, or composites thereof, or any other combinations thereof. Polymers may include both thermoplastic polymers or thermoset polymers, or composites thereof, or any other combinations thereof, including a wide variety of co-polymers and polymer blends. In one embodiment, a preferred plastic material is one having elastic properties so as to deform elastically without fracture, as for example, a material comprising an acrylonitrile butadiene styrene (ABS) polymer, and more particularly a polycarbonate ABS polymer blend (PC/ABS). The material may be in any form and formed or manufactured by any suitable process, including stamped or formed metal, composite or other sheets, forgings, extruded parts, pressed parts, castings, or molded parts and the like, to include the deformable features described herein. The elastically deformable alignment features and associated component may be formed in any suitable manner. For example, the elastically deformable alignment features and the associated component may be integrally formed, or they may be formed entirely separately and subsequently attached together. When integrally formed, they may be formed as a single part from a plastic injection molding machine, for example. When formed separately, they may be formed from different materials to provide a predetermined elastic response characteristic, for example. The material, or materials, may be selected to provide a predetermined elastic response characteristic of any or all of the elastically deformable alignment features, the associated component, or the mating component. The predetermined elastic response characteristic may include, for example, a predetermined elastic modulus.

As used herein, the term vehicle is not limited to just an automobile, truck, van or sport utility vehicle, but includes any self-propelled or towed conveyance suitable for transporting a burden.

In accordance with an exemplary embodiment of the invention, and with reference to FIG. 1, an elastically averaging alignment system 10 includes a first component 100 having a first alignment member 102 and an elastically deformable alignment element 104 fixedly disposed with respect to the

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first alignment member **102**, and a second component **200** having a second alignment member **202** and an alignment feature **204** fixedly disposed with respect to the second alignment member **202**. The elastically deformable alignment element **104** is configured and disposed to interferingly, deformably and matingly engage the alignment feature **204**, in a manner discussed in more detail below, to precisely align the first component **100** with the second component **200** in four directions, such as the \pm -x-direction and the \pm -y-direction of an orthogonal coordinate system, for example, which is herein referred to as four-way alignment. In an embodiment, the elastically deformable alignment element **104** is a lobular hollow tube (also herein referred to by reference numeral **104**) with a cross-section having at least three outwardly oriented lobes **106.1**, **106.2**, **106.3** relative to a central axis **108** of the lobular hollow tube **104** (best seen with reference to FIG. 2), and the alignment feature **204** is a circular aperture (also herein referred to by reference numeral **204**). In an embodiment, a chamfer **206** circumscribes the circular aperture **204** to facilitate insertion of the elastically deformable alignment element **104** into the circular aperture **204**.

While reference is made herein and illustrations are depicted herein with the elastically deformable alignment element **104** having just three outwardly oriented lobes **106.1**, **106.2**, **106.3** in a tri-lobular hollow tube arrangement, it will be appreciated that the scope of the invention is not so limited and also encompasses other numbers of outwardly oriented lobes, such as four, five, or more lobes that are suitable for a purpose disclosed herein. However, for discussion purposes a tri-lobular arrangement will be used, without limitation, to describe in detail the principles of the invention disclosed herein.

For discussion purposes, the mating side of the first alignment member **102** visible in FIG. 1 is labeled **12**, and the mating side of the second alignment member **202** visible in FIG. 1 is labeled **22**. The non-visible sides of the first and second alignment members **102**, **202** that are hidden from view in FIG. 1 are herein referred to by reference labels **11** and **21**, respectively. For discussion purposes, the **12** and **22** sides are herein referred to as front views, and the **11** and **21** sides are herein referred to as rear views. Dashed lines **20** represent direction lines that may be traversed as the first and second components **100**, **200** are assembled with respect to each other.

While not being limited to any particular structure, the first component **100** may be a decorative trim component of a vehicle with the customer-visible side being the **11** side, and the second component **200** may be a supporting substructure that is part of or attached to the vehicle and on which the first component **100** is fixedly mounted in precise alignment.

In an embodiment, the three outwardly oriented lobes **106.1**, **106.2**, **106.3** of the tri-lobular hollow tube **104** form three apex wall portions (also herein referred to by reference numerals **106.1**, **106.2**, **106.3**) that are equally distributed about the central axis **108** of the tri-lobular hollow tube **104**, with three connecting wall portions **106.4**, **106.5**, **106.6** integrally interconnected therebetween. In an embodiment, the three connecting wall portions **106.4**, **106.5**, **106.6** have flat planar outer surfaces. However, in another embodiment the three connecting wall portions **106.4**, **106.5**, **106.6** may be curved inward toward the central axis **108** of the tri-lobular hollow tube **104**, may be curved outward away from the central axis **108** of the tri-lobular hollow tube **104**, or may be a combination of inward curving and outward curving wall portions, which will be discussed further below.

Reference is now made to FIGS. 1, 2 and 3 in combination, where FIG. 2 depicts a front plan view of the first component

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100 with the **12** side visible, and FIG. 3 depicts a rear plan view of the second component **200** with the **21** side visible. The dashed-line circle **110** depicted in FIG. 2 represents an imaginary smallest diameter aperture that the three outwardly oriented lobes **106.1**, **106.2**, **106.3** of the elastically deformable alignment element **104** could slidably fit into without interference and without any deformation of the elastically deformable alignment element **104**. The dashed-line circle depicted in FIG. 3 is the chamfer **206** that is hidden from view from the **21** side, but is visible from the **22** side as depicted in FIG. 1. To provide an arrangement where the elastically deformable alignment element **104** is configured and disposed to interferingly, deformably and matingly engage the alignment feature **204**, the diameter of the circular aperture (also herein referred to by reference numeral **204**) is less than the diameter of the dashed-line circle **110**, which necessarily creates a purposeful interference fit between the elastically deformable alignment element **104** and the alignment feature **204**, and more particularly a purposeful interference fit between each lobe **106.1**, **106.2**, **106.3** and the circular aperture **204**. As such, portions of the elastically deformable alignment element **104**, such as the three outwardly oriented lobes **106.1**, **106.2**, **106.3**, when inserted into the alignment feature **204** elastically deform to an elastically averaged final configuration that aligns the first alignment member **102** with the second alignment member **202** in four planar orthogonal directions (the \pm -x-direction and the \pm -y-direction). The aforementioned deformation of the elastically deformable alignment element **104** will now be discussed with reference to FIGS. 4-5.

FIGS. 4 and 5 each depict a partial plan view of an assembly **15** of the first component **100** mated with the second component **200** where the elastically deformable alignment element **104** is interferingly, deformably and matingly engaged with the alignment feature **204**, as viewed from the **21** side of the second alignment member **202** (hidden line portion of chamfer **206** omitted for clarity). In FIGS. 4 and 5, the dashed lines represent a pre-engagement shape of the tri-lobular hollow tube **104**, and the correlating solid lines represent a post-engagement shape of the tri-lobular hollow tube **104**. As previously described, outer surfaces of the three apex wall portions **106.1**, **106.2**, **106.3** are sized to create an interference fit with the circular aperture **204**, and in accordance with an embodiment of the invention the connecting wall portions **106.4**, **106.5**, **106.6** are sized to fit within the circular aperture **204** with a clearance "d" therebetween (depicted in only one location, but understood to apply to all three similar locations), where "d" is equal to or greater than zero ($d \geq 0$). In the embodiment depicted in FIG. 4, the connecting wall portions **106.4**, **106.5**, **106.6** are configured to elastically deform away from the central axis **108** of the tri-lobular hollow tube **104**. In the embodiment of FIG. 5, the connecting wall portions **106.4**, **106.5**, **106.6** are configured to elastically deform toward the central axis **108** of the tri-lobular hollow tube **104**. As can be seen, the pre-engagement shape of the tri-lobular hollow tube **104** is depicted having an interference dimension "e" between each of the three apex wall portions **106.1**, **106.2**, **106.3** and the circular aperture **204**, where "e" is greater than zero ($e > 0$). While FIGS. 4 and 5 both depict the connecting wall portions **106.4**, **106.5**, **106.6** all deforming in a same direction (all outward in FIG. 4, and all inward in FIG. 5), it will be appreciated that the scope of the invention is not so limited and also encompasses an embodiment where the connecting wall portions **106.4**, **106.5**, **106.6** are configured to elastically deform in a com-

bined arrangement that includes elastic deformation toward and away from the central axis **108** of the tri-lobular hollow tube **104**.

In the embodiment depicted in FIG. 4 where the connecting wall portions **106.4**, **106.5**, **106.6** all deform outward during assembly of the first and second components **100**, **200**, it will be appreciated that an embodiment involves an arrangement where an outer perimeter **136** of a pre-engaged tri-lobular hollow tube **104** (best seen with reference to FIG. 2) must have a length that is less than a circumference of the circular aperture **204** in order to permit, albeit with elastically averaged deformation, insertion of the tri-lobular hollow tube **104** into the circular aperture **204** when the tri-lobular hollow tube **104** is interferingly, deformably and matingly engaged with the circular aperture **204** with outward deformation of the connecting wall portions **106.4**, **106.5**, **106.6**. That is, when the connecting wall portions **106.4**, **106.5**, **106.6** of the tri-lobular hollow tube **104** are outwardly deformed by compression of the apex wall portions **106.1**, **106.2**, **106.3** such that the connecting wall portions and apex wall portions completely fill the opening of the circular aperture **204**, the outer perimeter **136** of the now deformed tri-lobular tube **104** must be sized to fit within the opening of the circular aperture **204**, and therefore the outer perimeter **136** of the tri-lobular hollow tube **104** must be smaller in length than the circumference of the circular aperture **204** in order to avoid a line-on-line interference condition of the engaging surfaces.

As previously described, and in a pre-engagement shape, the three connecting wall portions **106.4**, **106.5**, **106.6** of the tri-lobular hollow tube **104** may have a predefined shape that curves inward toward the central axis **108**, or may have a predefined shape that curves outward away from the central axis **108**. Such predefined pre-engagement shapes of the three connecting wall portions **106.4**, **106.5**, **106.6** of the elastically deformable alignment element **104** serves to facilitate bending either inward or outward of the three connecting wall portions **106.4**, **106.5**, **106.6** during assembly of the first and second components **100**, **200** where the elastically deformable alignment element **104** is interferingly, deformably and matingly engaged with the alignment feature **204**.

In an embodiment, and with reference back to FIG. 1, the tri-lobular hollow tube **104** includes a proximal end **112** proximate the first alignment member **102** and a distal end **114** distal to the first alignment member **102**, and further includes a taper **140** (best seen with reference to FIG. 12) at the distal end, which may be created by a draft angle formed on the walls of a plastic injection molding machine configured to mold the first component **100** with integrally formed tri-lobular hollow tube **104**, for example, or may be created by a chamfer formed on the distal end **114** of the tri-lobular hollow tube **104**.

While FIG. 1 depicts just a single elastically deformable alignment element **104** in a corresponding circular aperture **204** to provide four-way alignment of the first component **100** relative to the second component **200**, it will be appreciated that the scope of the invention is not so limited and encompasses other quantities and types of elastically deformable alignment elements used in conjunction with the elastically deformable alignment element **104** and corresponding circular aperture **204**, which will now be discussed with reference to FIGS. 6-8.

FIG. 6 depicts a plan view of an assembly **25** of the first component **100** mated with the second component **200** as viewed from the **21** side of the second alignment member **202** (hidden line portion of chamfer **206** omitted for clarity) similar to that of FIGS. 1 and 4, but with first and second spaced-apart elastically deformable alignment elements (tri-lobular

hollow tubes) **104.1**, **104.2** interferingly, deformably and matingly engaged with corresponding spaced-apart alignment features (circular apertures) **204.1**, **204.2** being depicted in solid lines, and optional third and fourth spaced-apart elastically deformable alignment elements (tri-lobular hollow tubes) **104.3**, **104.4** interferingly, deformably and matingly engaged with corresponding spaced-apart alignment features (circular apertures) **204.3**, **204.4** being depicted in dashed lines.

In the embodiment of FIG. 6, the top edge **116** and left edge **118** at the top-left corner **120** of the first component **100** (best seen with reference also to FIG. 1 as the features of the first component **100** are hidden behind the second component **200** in FIG. 6) are controlled relative to the second component **200** by the four-way locating function of the first alignment element and feature **104.1**, **204.1**, and the top edge **116** and right edge **122** at the top-right corner **124** of the first component **100** (again best seen with reference also to FIG. 1) are controlled relative to the second component **200** by the four-way locating function of the second alignment element and feature **104.2**, **204.2**. The optional third and fourth alignment elements and features **104.3**, **204.3** and **104.4**, **204.4**, if and when used, provide similar four-way locating means for the bottom edge **126** and left edge **118** at the bottom-left corner **128**, and the bottom edge **126** and right edge **122** at the bottom-right corner **130**, respectively, of the first component **100** relative to the second component **200**. From the foregoing it will be appreciated that each of the first, second, third and fourth elastically deformable alignment elements **104.1**, **104.2**, **104.3**, **104.4**, when employed and when inserted into respective ones of the first, second, third and fourth alignment features **204.1**, **204.2**, **204.3**, **204.4**, elastically deform in a manner previously described herein to an elastically averaged final configuration that further aligns the first alignment member **102** with the second alignment member **202** in four planar orthogonal directions (+/-x-direction and +/-y-direction).

As a brief aside and in view of the foregoing discussion, it will be appreciated that an outer edge, such as the top edge **116** for example, of the first alignment member **102** of the first component **100** may be outboard of, inboard of, or in alignment with the corresponding edge of the second alignment member **202** of the second component **200**, depending on the application that could advantageously benefit from use of the elastically averaging alignment system **10** disclosed herein. In the embodiment of FIG. 6, the outer edges (**116**, **118**, **122**, **126**) of the first alignment member **102** are depicted in alignment with the corresponding edges of the second alignment member **202**, but it will be understood that such an arrangement is not a limitation to the scope of the invention disclosed herein.

Reference is now made to FIG. 7, which depicts a plan view of an assembly **30** of the first component **100** mated with the second component **200** as viewed from the **21** side of the second alignment member **202** (hidden line portion of chamfer **206** omitted for clarity) similar to that of FIGS. 1 and 4, but with the first alignment element (tri-lobular hollow tube) **104** and first alignment feature (circular aperture) **204** accompanied by a spaced-apart second elastically deformable alignment element **304** in the form of a circular hollow tube that is interferingly, deformably and matingly engaged with a corresponding spaced-apart second alignment feature **404** in the form of a slotted aperture, similar to the elastic tube alignment system described in co-pending U.S. patent application Ser. No. 13/187,675 and particularly illustrated in FIG. 13 of the same, which is herein incorporated by reference in its entirety. As depicted in FIG. 7, the slotted aperture **404** has its major

axis **408** oriented orthogonal to the central axis **108** of the tri-lobular hollow tube **104**, which in conjunction with the four-way alignment function provided by the first alignment element and feature **104**, **204**, further provides a two-way alignment function in a direction perpendicular to the major axis **408**.

While the major axis **408** of the slotted aperture **404** is depicted in FIG. 7 to be oriented directly towards the central axis **108** of the tri-lobular hollow tube **104**, it will be appreciated that such an orientation may not be necessary or practical in some situations, and that an embodiment includes an arrangement where the major axis **408** of the slotted aperture **404** is oriented more toward than away from the central axis **108** of the tri-lobular hollow tube **104** without departing from a scope of the invention disclosed herein.

In the embodiment of FIG. 7, the second alignment element and feature **304**, **404** serve to angularly orient, in the x-y plane and with respect to the central axis **108** of the tri-lobular hollow tube **104**, the first alignment member **102** of the first component **100** relative to the second alignment member **202** of the second component **200**, by configuring and disposing the second elastically deformable alignment element (circular hollow tube) **304** to interferingly, deformably and matingly engage with the second alignment feature (slotted aperture) **404** in a compressive mode but not in a bending mode.

Reference is now made to FIG. 8, which depicts a plan view of an assembly **35** of the first component **100** mated with the second component **200** as viewed from the **21** side of the second alignment member **202** (hidden line portion of chamfer **206** omitted for clarity) similar to that of FIGS. 1, 4 and 7, but with the first alignment element (tri-lobular hollow tube) **104** and first alignment feature (circular aperture) **204** accompanied by spaced-apart second and third elastically deformable alignment elements **504**, **604** each in the form of a circular hollow tube that is interferingly, deformably and matingly engaged with corresponding and respective spaced-apart second and third alignment features **704**, **804** each in the form of a slotted aperture, similar to the elastic tube alignment system described in co-pending U.S. patent application Ser. No. 13/187,675 and particularly illustrated in FIG. 13 of the same. As depicted in FIG. 8, each slotted aperture **704**, **804** has its major axis **708**, **808** oriented in a plane orthogonal to the central axis **108**, but not oriented orthogonal to the central axis **108**, of the tri-lobular hollow tube **104**, which in conjunction with the four-way alignment function provided by the first alignment element and feature **104**, **204**, further provides a two-way alignment function in a direction perpendicular to the major axes **708**, **808** and perpendicular to the lower edge **126** of the first component **100** (see also FIG. 1 for depiction of lower edge **126**).

While the major axes **708**, **808** of respective slotted apertures **704**, **804** are depicted oriented parallel to a lower edge **126** of the first component **100**, it will be appreciated that such an orientation may not be necessary or practical in some situations, and that an embodiment includes an arrangement where each major axis **708**, **808** of the slotted apertures **704**, **804** are oriented more parallel with than perpendicular to the lower edge **126** (in more general terms, the lower edge **126** may be considered an outer edge that is associated with the respective second and third alignment elements and features), which from an alternative perspective provides an arrangement where each major axis **708**, **808** of the respective slotted apertures **704**, **804** is oriented more away from than toward the central axis **108** of the tri-lobular hollow tube **104**, without departing from a scope of the invention disclosed herein.

In the embodiment of FIG. 8, and consistent with the elastic tube alignment system described in co-pending U.S. patent

application Ser. No. 13/187,675, the second and third elastically deformable alignment elements (circular hollow tubes) **504**, **604** may be centrally disposed closer to the central axis **108** of the tri-lobular hollow tube **104** than the major axes **708**, **808** of the slotted apertures **704**, **804** are disposed relative to the center of the circular aperture **204**, thereby resulting in an interference fit and a slight bending of the circular hollow tubes **504**, **604** as they are interferingly, deformably and matingly engaged with respective ones of the slotted apertures **704**, **804**. As such, the embodiment of FIG. 8 serves to accurately locate the lower edge **126** of the first alignment member **102** with the respective lower edge (also herein referred to by reference numeral **126**) of the second alignment member **202** by configuring and disposing the second and third elastically deformable alignment elements (circular hollow tubes) **504**, **604** to interferingly, deformably and matingly engage with the respective second alignment features (slotted apertures) **704**, **804** in a compressive mode and in a bending mode. To assist with the engagement of the circular hollow tubes **504**, **604** with the slotted apertures **704**, **804** in the manner herein described, the **22** side of the second alignment member **202** may be provided with a chamfer disposed around the perimeter of each slotted aperture **704**, **804**, which is not specifically illustrated herein but is consistent with the elastic tube alignment system described in co-pending U.S. patent application Ser. No. 13/187,675.

Reference is now made to FIGS. 9 and 10, which depict distal end plan views of alternative tri-lobular hollow tubes **104'**, **104''** consistent with an embodiment of the invention disclosed herein. Both versions of the tri-lobular hollow tubes **104'**, **104''** have connecting wall portions **106.4**, **106.5**, **106.6** that are thinner in the middle section than at the end sections, as indicated by references "t" and "T", where $t < T$, or more generally where $t \neq T$. In the embodiment of FIG. 9, the outer surfaces of the connecting wall portions **106.4**, **106.5**, **106.6** are convex with respect to the central axis **108** of the tri-lobular hollow tube **104'**, which is contemplated to facilitate elastic deformation of the tri-lobular hollow tube **104'** in the manner depicted in FIG. 5. In the embodiment of FIG. 10, the inner surfaces of the connecting wall portions **106.4**, **106.5**, **106.6** are concave with respect to the central axis **108** of the tri-lobular hollow tube **104''**, which is contemplated to facilitate elastic deformation of the tri-lobular hollow tube **104''** in the manner depicted in FIG. 4. By controlling the direction of elastic deformation of the connecting wall portions **106.4**, **106.5**, **106.6** (inward or outward for example), it is contemplated that the overall elastic averaging achieved by the elastically averaging alignment system **10** will be more predictable as compared to a system having elastic deformation in random directions.

Reference is now made to FIGS. 11 and 12, where FIG. 11 depicts an alternative front plan view (**12** side) of the first component **100** similar to that of FIG. 1, but with standoffs **138** (six illustrated but only one enumerated) integrally formed with the first alignment member **102** and distributed around the central axis **108** of the lobular hollow tube **104**, and where FIG. 12 depicts a section cut **12-12** through FIG. 11 with the second component **200** depicted in dashed line fashion. The standoffs **138** are spaced relative to the outer diameter of the chamfer **206** (also seen with reference to FIG. 3) of the second alignment member **202** such that they provide a support platform at a height "h" above the **12** side of the first component **100** upon which the **22** side of the second component **200** rests when the elastically deformable alignment element **104** is configured and disposed to interferingly, deformably and matingly engage the alignment feature **204** (best seen with reference to FIG. 12). Stated alternatively, the

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standoffs 138 are disposed and configured to provide a point of engagement between the alignment feature 204 and the elastically deformable alignment element 104 at an elevation “h” above the base, surface 12, of the elastically deformable alignment element 104.

While FIG. 11 depicts six standoffs 138 in the form of circular posts at a height “h” relative to the 12 side of the first component 100, it will be appreciated that the scope of the invention is not so limited and also encompasses other numbers and shapes of standoffs suitable for a purpose disclosed herein, and also encompasses a standoff in the form of a continuous ring disposed around the lobular hollow tube 104. All such alternative standoff arrangements are contemplated and considered within the scope of the invention disclosed herein.

While FIG. 11 depicts standoffs 138 integrally formed on the 12 side of the first component 100, it will be appreciated that a similar function may be achieved by integrally forming the standoffs on the 22 side of the second component 200, which is herein contemplated and considered to be within the scope of the invention disclosed herein.

In an embodiment, and as depicted in FIG. 12, the depth “D” of the lobular hollow tube 104 has a bottom surface that is in-line with the 12 side of the first component 100. By providing standoffs 138 that elevate a point of engagement between the alignment feature 204 and the elastically deformable alignment element 104 relative to the 12 side of the first component 100, a degree of elastic deformation of the elastically deformable alignment element 104 suitable for a purpose disclosed herein can be achieved. If the standoffs 138 were omitted and the 22 side of the second component 200 was permitted to rest on the 12 side of the first component 100 where the apex and connecting wall portions of the lobular hollow tube 104 meet with the base material of the first alignment member 102, the rigidity of such wall portions at the base of the lobular hollow tube 104 would be too stiff in bending to provide a degree of elastic deformation suitable for a purpose disclosed herein. As such, a standoff arrangement as herein disclosed, or an arrangement having the functional equivalent, is advantageous for providing a degree of elastic deformation of the elastically deformable alignment element 104 suitable for a purpose disclosed herein.

As can be seen in FIG. 12, the apex wall portion 106.2 of the lobular hollow tube 104 engages with the circular aperture 204, while in an embodiment the connecting wall portion 106.6 has a gap “d” with respect to the circular aperture 204, which is consistent with the embodiment depicted in FIG. 4.

In view of all of the foregoing, and with reference now to FIG. 13, it will be appreciated that an embodiment of the invention also includes a vehicle 40 having a body 42 with an elastically averaging alignment system 10 as herein disclosed integrally arranged with the body 42. In the embodiment of FIG. 13, the elastically averaging alignment system 10 is depicted forming at least a portion of a front grill of the vehicle 40. However, it is contemplated that an elastically averaging alignment system 10 as herein disclosed may be utilized with other features of the vehicle 40, such as interior trim for example.

In view of the foregoing, it will be appreciated that some embodiments of the elastically averaging alignment system disclosed herein may include one or more of the following advantages: an elastically deformable alignment system utilizing a single elastically deformable alignment element that provides four-way alignment with only three regions of interference when engaged with a corresponding single alignment feature having the form of a circular aperture; an elastically deformable alignment system that provides four-way align-

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ment via a four-way elastically deformable alignment system, and two-way alignment absent a bending mode when combined with a two-way elastically deformable alignment system having a slotted aperture with a major axis oriented more toward than away from the four-way elastically deformable alignment system; an elastically deformable alignment system that provides four-way alignment via a four-way elastically deformable alignment system, and two-way alignment with a bending mode when combined with a two-way elastically deformable alignment system having a slotted aperture with a major axis oriented more away from than toward the four-way elastically deformable alignment system; and, an elastically deformable alignment system utilizing a lobular hollow tube alignment element with a variable wall thickness that provides a predictable direction of elastic deformation of the lobular hollow tube walls for predictable elastic averaging deformation.

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the application.

What is claimed is:

1. An elastically averaged alignment system, comprising: a first component comprising a first alignment member and an elastically deformable alignment element fixedly disposed with respect to the first alignment member; a second component comprising a second alignment member and an alignment feature fixedly disposed with respect to the second alignment member; wherein the elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the alignment feature; wherein the elastically deformable alignment element comprises a lobular hollow tube having a cross-section comprising at least three outwardly oriented lobes relative to a central axis of the hollow tube, and the alignment feature comprises a circular aperture; and wherein portions of the elastically deformable alignment element when inserted into the alignment feature elastically deform to an elastically averaged final configuration that aligns the first alignment member with the second alignment member in four planar orthogonal directions; wherein the lobular hollow tube comprises a tube wall having three apex wall portions equally distributed about a central axis of the lobular hollow tube and three connection wall portions interconnected between the apex wall portions, wherein the apex wall portions are sized to create an interference fit with the circular aperture, wherein the connecting wall portion are sized to fit within the circular aperture with clearance therebetween, and wherein the connecting wall portions are configured to elastically deform toward the central axis of the lobular hollow tube, away from the central axis of the lobular hollow tube, or in combination that includes elastic deformation toward and away from the central axis of the lobular hollow tube.
2. The elastically averaged alignment system of claim 1, wherein the lobular hollow tube comprises a tri-lobular hollow tube.

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3. The elastically averaged alignment system of claim 1, wherein the diameter of the circular aperture is sized to create an interference fit with each lobe of the lobular hollow tube.

4. The elastically averaged alignment system of claim 1, wherein the three connecting wall portions are curved inward toward the central axis of the lobular hollow tube.

5. The elastically averaged alignment system of claim 1, wherein the three connecting wall portions are curved outward away from the central axis of the lobular hollow tube.

6. The elastically averaged alignment system of claim 1, wherein an outer perimeter of the lobular hollow tube has a length that is less than a circumference of the circular aperture.

7. The elastically averaged alignment system of claim 1, wherein the elastically deformable alignment element is integrally formed with the first alignment member to form a single part.

8. The elastically averaged alignment system of claim 1, wherein the alignment feature is integrally formed with the second alignment member to form a single part.

9. The elastically averaged alignment system of claim 1, wherein the first component and the second component each have respective engagement sides relative to each other, and further wherein:

the second alignment member comprises a chamfer on its respective engagement side that circumscribes the circular aperture.

10. The elastically averaged alignment system of claim 1, wherein the first component and the second component each have respective engagement sides relative to each other, and further wherein:

the lobular hollow tube of the elastically deformable alignment element comprises a proximal end proximate the first alignment member and a distal end distal to the first alignment member; and

the distal end comprises a taper on its respective engagement side.

11. The elastically averaged alignment system of claim 1, wherein the elastically deformable alignment element is a first of a plurality of the elastically deformable alignment element, wherein the alignment feature is a first of a plurality of the alignment feature, and further comprising:

a second of the plurality of the elastically deformable alignment element fixedly disposed with respect to the first alignment member and spaced apart from the first of the plurality of elastically deformable alignment element;

a second of the plurality of the alignment feature fixedly disposed with respect to the second alignment member and spaced apart from the first of the plurality of the alignment feature;

wherein the second of the plurality of the elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the second of the plurality of the alignment feature; and wherein portions of each of the first and second of the plurality of the elastically deformable alignment elements when inserted into respective ones of the first and second of the plurality of the alignment features elastically deform to an elastically averaged final configuration that further aligns the first alignment member with the second alignment member in four planar orthogonal directions.

12. The elastically averaged alignment system of claim 1, wherein the elastically deformable alignment element is a first elastically deformable alignment element and the alignment feature is a first alignment feature, and further wherein:

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the first alignment member further comprises a second elastically deformable alignment element comprising a hollow tube having a circular cross-section relative to a central axis thereof, the second elastically deformable alignment element being spaced apart from the first elastically deformable alignment element;

the second alignment member further comprises a second alignment feature comprising a slotted aperture spaced apart from the first alignment feature, the slotted aperture having a major axis oriented orthogonal to a central axis of the first alignment feature; and

wherein the second elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the second alignment feature in a compressive mode and not in a bending mode.

13. The elastically averaged alignment system of claim 1, wherein the elastically deformable alignment element is a first elastically deformable alignment element and the alignment feature is a first alignment feature, and further wherein:

the first alignment member further comprises a second elastically deformable alignment element comprising a hollow tube having a circular cross-section relative to a central axis thereof, the second elastically deformable alignment element being spaced apart from the first elastically deformable alignment element;

the second alignment member further comprises a second alignment feature comprising a slotted aperture spaced apart from the first alignment feature, the slotted aperture having a major axis oriented in a plane orthogonal to a central axis of the first alignment feature; and

wherein the second elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the second alignment feature in a compressive and in a bending mode.

14. The elastically averaged alignment system of claim 1, wherein:

at least one of the first component and the second component comprises a standoff disposed proximate the elastically deformable alignment element, and disposed and configured to provide a point of engagement between the alignment feature and the elastically deformable alignment element at an elevation "h" above the base of the elastically deformable alignment element.

15. A vehicle, comprising:

a body; and

an elastically averaged alignment system integrally arranged with the body, the elastically averaged alignment system comprising:

a first component comprising a first alignment member and an elastically deformable alignment element fixedly disposed with respect to the first alignment member;

a second component comprising a second alignment member and an alignment feature fixedly disposed with respect to the second alignment member;

wherein the elastically deformable alignment element is configured and disposed to interferingly, deformably and matingly engage the alignment feature;

wherein the elastically deformable alignment element comprises a lobular hollow tube having a cross-section comprising at least three outwardly oriented lobes relative to a central axis of the hollow tube, and the alignment feature comprises a circular aperture; and

wherein portions of the elastically deformable alignment element when inserted into the alignment feature elastically deform to an elastically averaged final configuration.

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tion that aligns the first alignment member with the second alignment member in four planar orthogonal directions;

wherein the lobular hollow tube comprises a tube wall having three apex wall portions equally distributed 5 about a central axis of the lobular hollow tube and three connection wall portions interconnected between the apex wall portions, wherein the apex wall portions are sized to create an interference fit with the circular aperture, wherein the connecting wall portions are sized to fit 10 within the circular aperture with clearance therebetween, and wherein the connecting wall portions are configured to elastically deform toward the central axis of the lobular hollow tube, away from the central axis of the lobular hollow tube, or in a combination that includes 15 elastic deformation toward and away from the central axis of the lobular hollow tube.

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